RECONFIGURABLE PHASED MICROSTRIP ANTENNA ARRAY WITH DEFECTED GROUND STRUCTURE AND DEFECTED MICROSTRIP STRUCTURE FOR BEAM STEERING APPLICATIONS

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Sincerely dedicated to my wife for her encouragement, love and support.
To the memory of my father and mother, who would have been glad to see me at this moment.

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ABSTRACT

Beam steering is defined as the ability to electronically steer the beam maximum of an antenna electric field pattern to some predefined point in space. The performance of a phased antenna array for beam steering without moving the antennas is important to military and civil applications. A steerable antenna with tuneable phase shifter continues to be a popular choice to provide such systems. However, this additional device makes the structure more complicated, bulky and it represent a great part of the production cost of a phased array antenna. Therefore, it creates new challenges to find an alternative approach. This work proposed two alternative approaches to steer the main beam. The first is based on a defected ground structure (DGS), while the second is a defected microstrip structure (DMS), which due to their slow wave effect and band-stop property, are able to disturb surface current distribution, then change the element phase and hence steer the main beam. This work started with investigating and applying new method for beam steering based on using DGS and DMS, where this reflects the first objective. As a second objective, this work proposed new approach for beam steering, where DGS is integrated between two patches for the bandwidth within X-band. The simulated results revealed the achievement of the target to steer the main beam to 50° along H-plane. For the third objective, a spiral antenna array (SAA) has been proposed, and it was observed that the best choice for selecting feed network for feeding circular antenna array is a common sequential feed network (SFN), which has a circular shape with four ports to feed four elements. In order to increase the number of ports and hence design suitable feed network for feeding SAA, this study proposed new spiral sequential feed network (SSFN). As a dual structure of DGS, and compared with DGS, DMS is of great advantage in design due to its reduced size and the feature of electromagnetic interference noise immunity. Furthermore, DMS has higher effective inductance compared to DGS. Therefore, this work proposed new reconfigurable SAA with DMS fed by SSFN within C-band. The simulated results showed the achievement of the target to steer the main beam to 61°

and 84° along E-plane and H-plane, respectively. Furthermore, as the last objective, a new approach was proposed for extracting equivalent circuit model for DGS with dual patches, SSFN and SAA. Two prototypes of dual patches with and without DGS, SSFN and two prototypes of SAA with DMS were fabricated for scattering parameter and far-field radiation pattern measurements. The results showed close agreement with the predicted results, where array with DGS confirmed a beam steering of 36° along H-plane, while SAA with DMS displayed 45° beam steering along E-plane, respectively. Future works will focus on increasing the array gain and reducing the array beamwidth which will give a clear vision for beam steering of array.

ABSTRAK

Kemudi pancaran bermaksud keupayaan untuk menggerakkan pancaran maksimum corak medan elektrik antena secara elektronik ke beberapa titik yang telah ditetapkan didalam sesuatu ruang. Keupayaan antena susunan berfasa mengesan tanpa menggerakkan antena sangat penting untuk aplikasi tentera dan awam. Antena yang boleh dikendalikan (*steerable antenna*) dengan peralihan fasa boleh laras menjadi pilihan utama dalam menyediakan sistem tersebut. Walau bagaimanapun, peralatan tambahan mengakibatkan struktur lebih rumit besar dan dan ia mempengaruhi sebahagian besar daripada kos pengeluaran antena susunan. Oleh itu, ia merupakan cabaran baru untuk mencari kaedah alternatif. Kajian ini mencadangkan dua pendekatan alternatif untuk mengubah pancaran utama (*beam steering*). Pertama, adalah berdasarkan *defected ground structure* (DGS), manakala untuk kaedah kedua adalah *defected microstrip structure* (DMS), di mana berdasarkan kesan gelombang perlahan dan ciri-ciri jalur berhenti mampu untuk mengganggu penyebaran permukaan arus elektrik, kemudian menukar fasa elemen dan akhirnya mengubah pancaran utama. Kajian ini dimulakan dengan menyiasat dan menggunakan kaedah baru untuk mengubah pancaran berdasarkan penggunaan DGS dan DMS, dimana ia dinyatakan dalam objektif pertama. Untuk objektif kedua, kajian ini mencadangkan pendekatan baru untuk mengubah pancaran, dimana DGS diintegrasikan diantara dua tampalan untuk jalur lebar diantara jalur-X. Hasil ujian simulasi menunjukkan sasaran berjaya mengubah pancaran utama kepada 50° sepanjang satah H. Untuk objektif ketiga pula, *spiral antenna array* (SAA) telah dicadangkan dan setelah diteliti, pilihan terbaik untuk rangkaian teknik suapan untuk suapan antena susunan bulat ialah *sequential feed network* (SFN) dimana mempunyai bentuk bulat serta empat input untuk suapan empat elemen. Untuk meningkatkan bilangan input, kajian ini mencadangkan *spiral sequential feed network* (SSFN) baru untuk reka bentuk rangkaian suapan yang sesuai untuk suapan SAA. Sebagai DGS dwi-struktur, dan berbanding dengan DGS, DMS mempunyai kelebihan yang besar dalam reka bentuk kerana saiznya yang lebih kecil

dan ciri elektromagnetiknya yang kebal terhadap gangguan. Selain itu, DMS mempunyai induktansi yang lebih tinggi berbanding DGS. Oleh itu, kajian ini mencadangkan, SAA yang boleh dikonfigurasikan berserta suapan DMS oleh SSFN dalam jalur-C. Hasil simulasi menunjukkan bahawa pencapaian sasaran untuk mengubah pancaran utama kepada 61° dan 84° di sepanjang satah E dan satah H, masing-masing. Di samping itu, untuk objektif yang terakhir, pendekatan baru telah dicadangkan untuk menghasilkan model litar setara untuk DGS berserta, SSFN dan SAA. Dua prototaip dwi-tampalan direka dengan dan tanpa DGS, SSFN SAA dan dua prototaip SAA berserta telah difabrikasi untuk ujian parameter berselerak dan corak radiasi bidang jauh. Keputusan menunjukkan persetujuan yang baik dengan hasil yang dijangkakan, dimana antena susunan berserta DGS mengubah pancaran 36° satah H, manakala SAA berserta DMS menunjukkan 45° perubahan pancaran sepanjang satah E, masing-masing. Kajian akan datang akan diberi tumpuan kepada peningkatan nilai gandaan (*gain*) antena susunan dan mengurangkan jalur lebar antena susunan dimana akan memberikan gambaran yang jelas untuk mengendalikan pancaran antena susunan.

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			Unit
r_c	-	Actual Radius of Circular Patch	mm
R_o	-	Additional Losses in the Equivalent Circuit Model	Ω
t	-	Angle in Polar Coordinate System	degree (°)
γ_{mn}	-	Angle Between Reference Direction of r and the Element Position of r_{mn}	degree (°)
ϖ_o	-	Angular Resonant Frequency	Hz
$AF(\theta)$	-	Array Factor One-Dimensional Array	
$AF(\theta,\Phi)$	-	Array Factor Two-Dimensional Array	
A	-	Area of the Circular Patch	mm^2
$S(t)$	-	Arc Length of the Archimedean Spiral Transformer	mm
Φ	-	Azimuth Angle	degree (°)
Φ_n	-	Azimuth Location of n Element	degree (°)
C_{cc1}	-	Capacitive Coupling Circuit Between Two Patches	F
C_{cc2}	-	Capacitive Coupling Circuit Between DGS and Ground Plane	F
C_{cc3}	-	Capacitive Coupling Circuit Between Two Patches and DGS	F
Z_c	-	Characteristics Impedance	Ω
Z_{c1}	-	Characteristics Impedance of only Rectangular Patch	Ω
Z_{c2}	-	Characteristics Impedance of Patch Feed Line	Ω
Z_o	-	Characteristics Impedance of Terminated Port	Ω
$Z_o^{\ slot}$	-	Characterized Impedance of Slot	Ω

			Unit
β	-	Constant Phase Shift	mm^{-1}
e	-	Constant in Polar Coordinate System	
α_n	-	Current Phase of the Element in One-Dimensional Array	degree (°)
α_{mn}	-	Current Phase of the Element in Two-Dimensional Array	degree (°)
fc	-	Cut-Off Frequency	Hz
$x'(t)$	-	Derivative of x with Respect to t	mm
$y'(t)$	-	Derivative of y with Respect to t	mm
L_v	-	DGS Vertical Slot Length	mm
L_h	-	DGS Horizontal Slot Length	mm
θ_o	-	Direction of the Maxim Beam Pattern in Elevation	degree (°)
Φ_o	-	Direction of the Maxim Beam Pattern in Azimuth	degree (°)
r_n	-	Distance Between Element Position and the Coordinate Origin 0 in Spiral and Conformal Array	mm
r_{mn}	-	Distance Between Element Position and the Coordinate Origin 0	mm
ε_r	-	Dielectric Constant	
R_{cc}	-	Distance Between Two Adjacent Elements from Center to Center in Spiral Antenna Array	mm
r_{ee}	-	Distance Between Two Adjacent Elements from Edge to Edge	mm
$f(\theta)$	-	Element Radiation Pattern in One-Dimensional Array	
$f(\theta,\Phi)$	-	Element Radiation Pattern in Two-Dimensional Array	
I_n	-	Element Excitation Current Amplitude in One-Dimensional Array	Ampere (A)

			Unit
I_{mn}	-	Element Excitation Current Amplitude inTwo-Dimensional Array	Ampere (A)
θ	-	Elevation Angle	degree (°)
θ_n	-	Elevation Location of n Element	degree (°)
E	-	Electric Field Vector	V/m
$A_{mn(x,y,z)}$	-	Element Location Mounted on a Cylinder	
φ_{mn}	-	Excitation Current Phase for Conformal Array with Uniform Elements Distribution	degree (°)
$j\alpha_n$	-	Excitation current phase for Conformal Array with Non-Uniform Elements Distribution	degree (°)
r_{ce}	-	Effective Radius of Circular Patch	mm
C_p	-	Equivalent Capacitance of Patch	F
L_p	-	Equivalent Inductance of Patch	H
R_p	-	Equivalent Resistance of Patch	Ω
C_a, C_b C_c C_d	-	Equivalent Capacitance of Slots a, b, c, and d within DGS, respectively	F
L_a L_b L_c L_d	-	Equivalent Inductance of Slots a, b, c, and d within DGS, respectively	H
R_a, R_b R_c R_d	-	Equivalent Resistance of Slots a, b, c, and d within DGS, respectively	Ω
C_{pDGS}	-	Equivalent Capacitance of DGS slot	F
L_{pDGS}	-	Equivalent Inductance of DGS slot	H
R_{pDGS}	-	Equivalent Resistance of DGS slot	Ω
C_1 C_2 C_3 C_4 C_5 C_6 C_7	-	Equivalent Capacitance Network Transformers (T_1- T_7), respectively	F
L_1 L_2 L_3 L_4 L_5 L_6 L_7	-	Equivalent Inductance Network Transformers (T_1- T_7), respectively	H
R_1 R_2 R_3 R_4 R_6 R_7	-	Equivalent Resistance Network Transformers (T_1- T_7), respectively	Ω

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